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(54) **SEMICONDUCTOR DEVICE WITH ENHANCED MOBILITY AND METHOD**

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USPC **257/329**; 257/E21.262

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USPC 257/328
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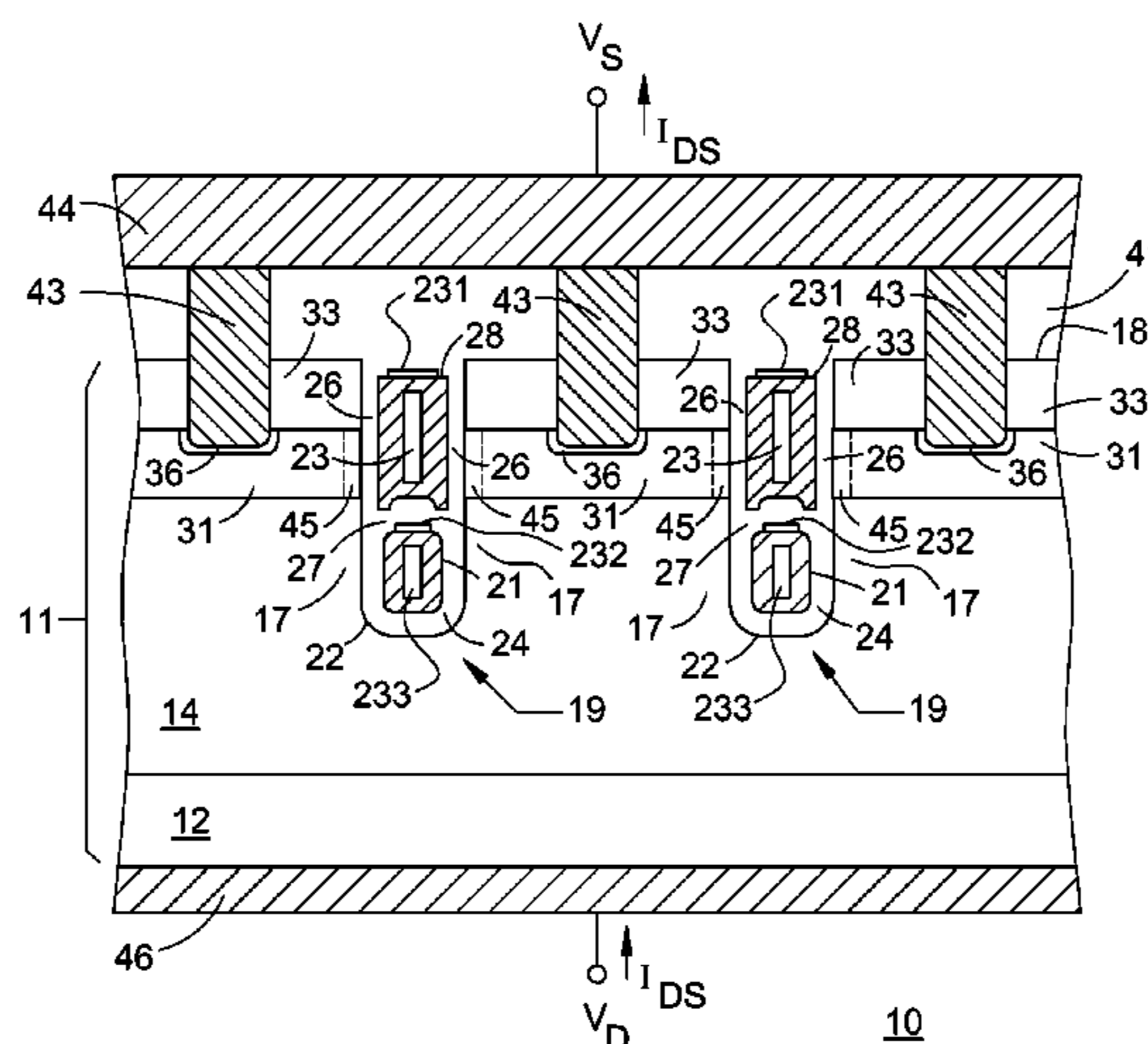
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(57) **ABSTRACT**

In one embodiment, a vertical insulated-gate field effect transistor includes a feature embedded within a control electrode. The feature is placed within the control electrode to induce stress within predetermined regions of the transistor.

19 Claims, 11 Drawing Sheets



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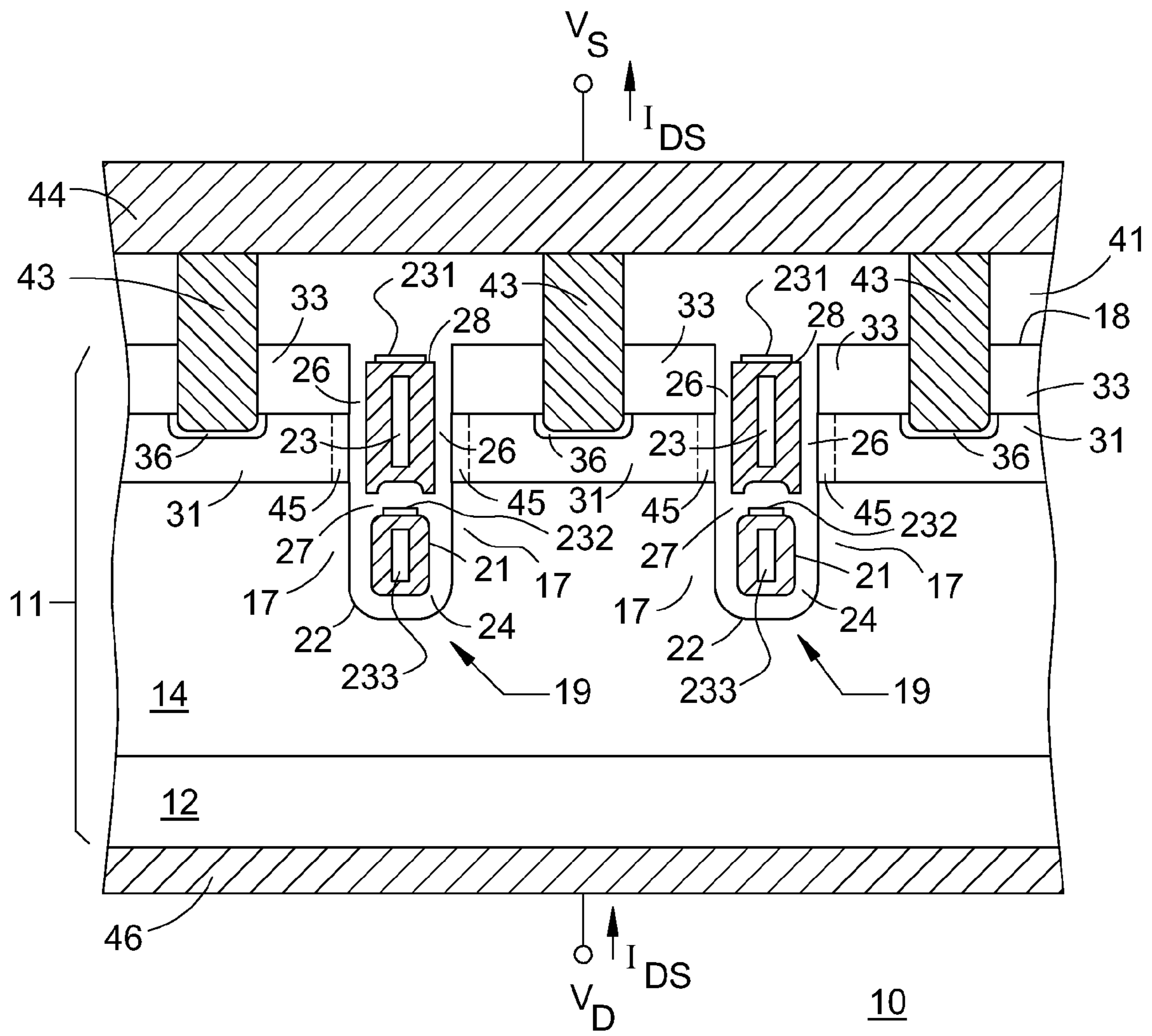


FIG. 1

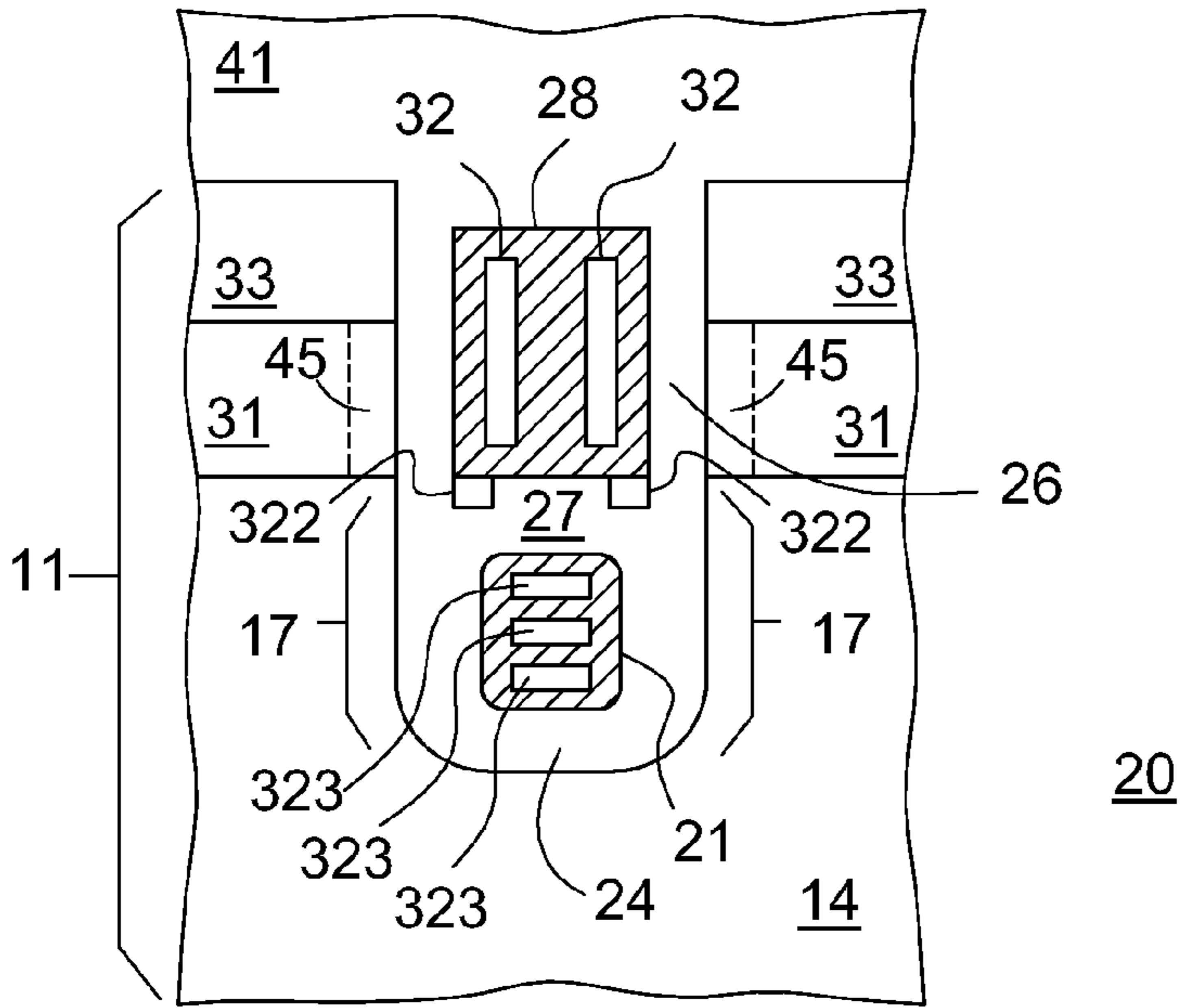
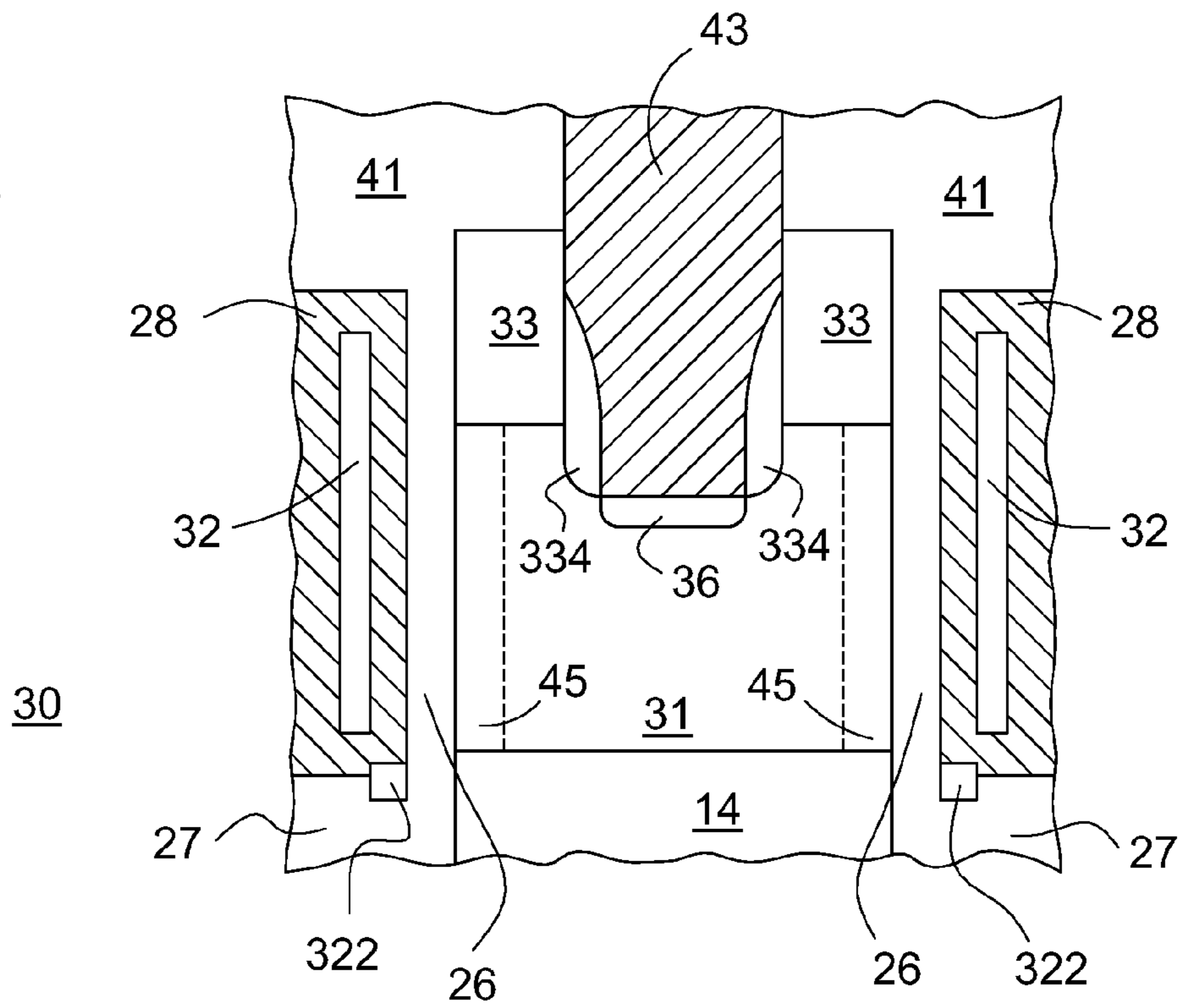


FIG. 2

FIG. 3



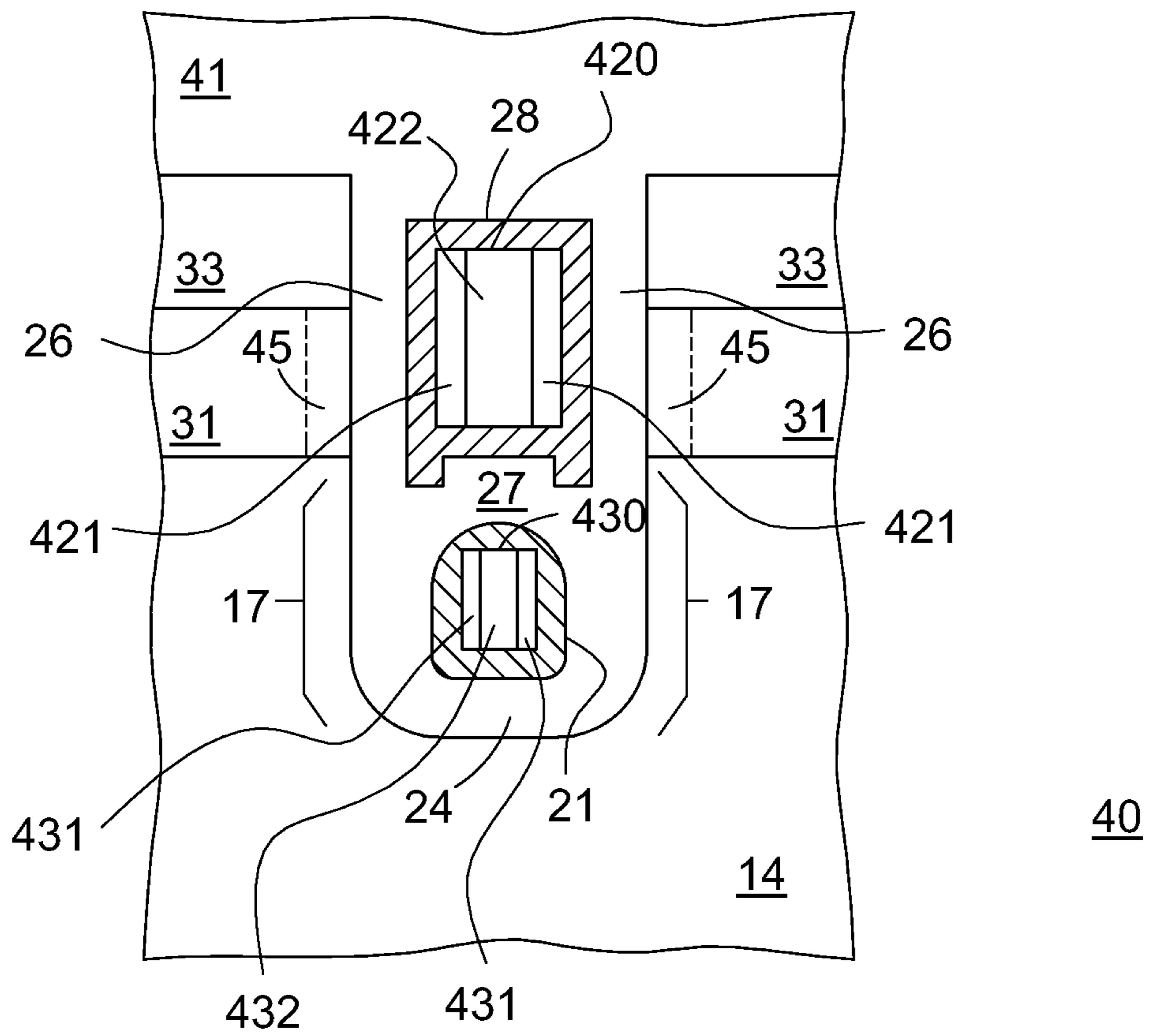


FIG. 4

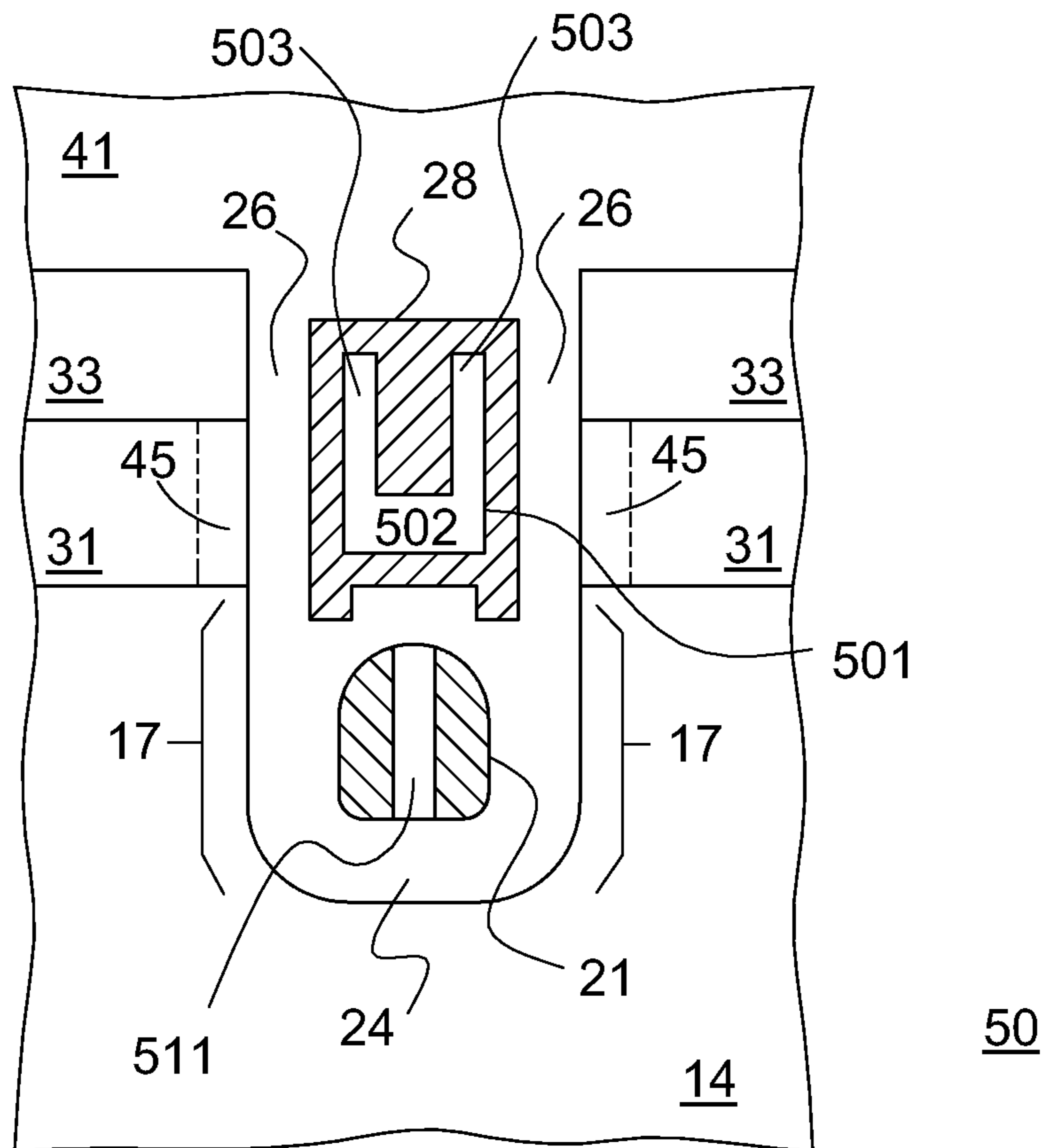


FIG. 5

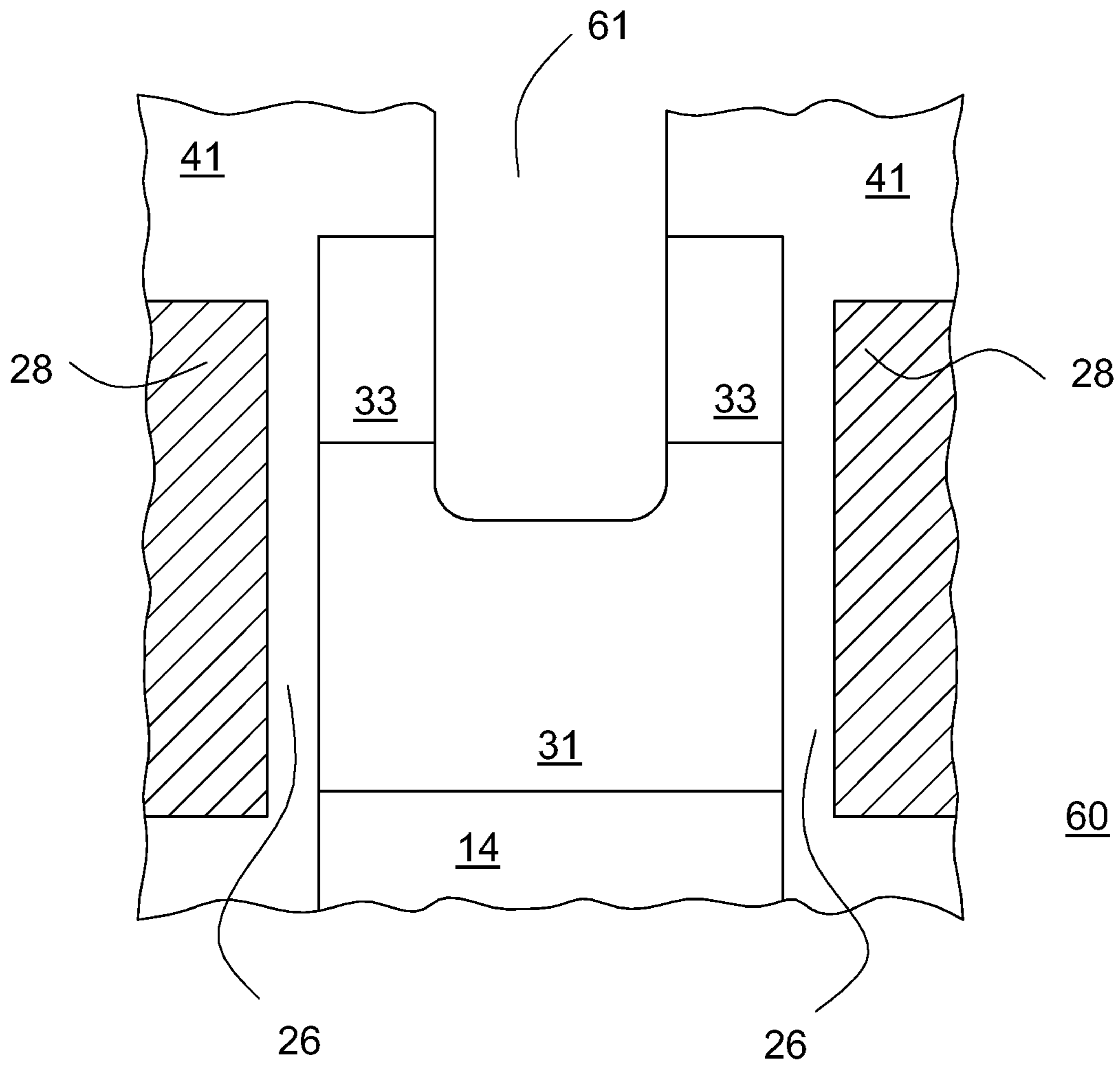


FIG. 6

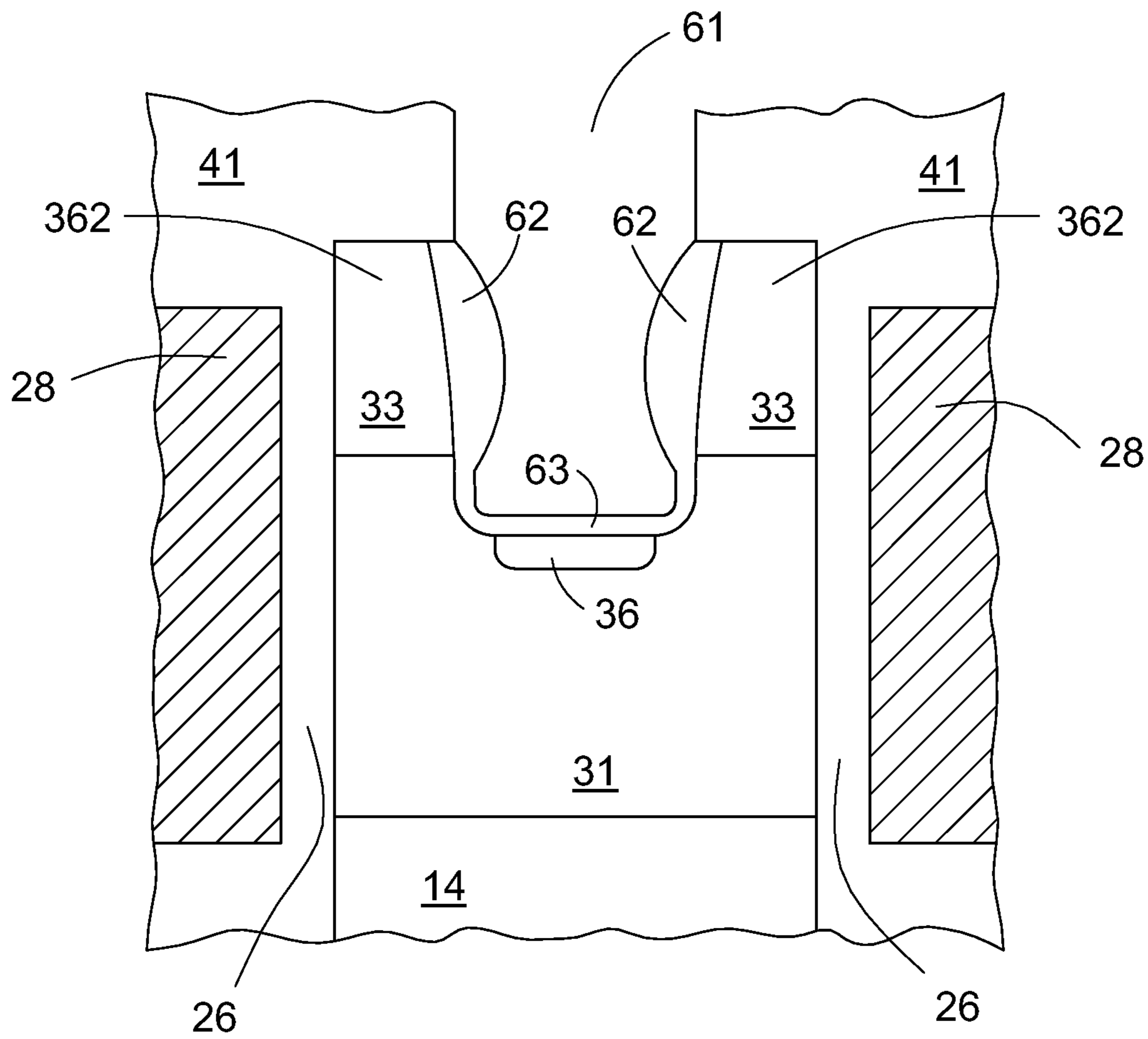


FIG. 7

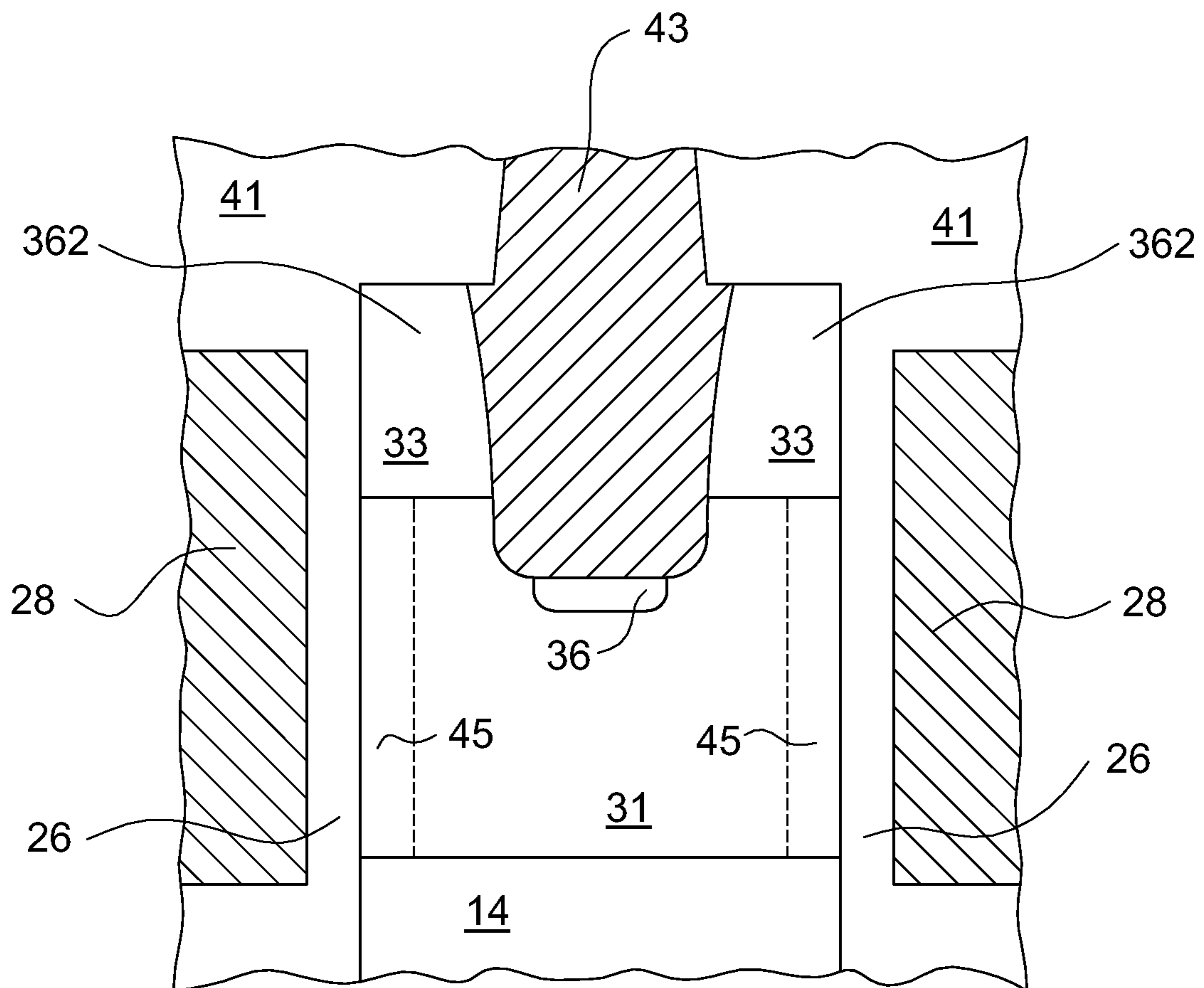


FIG. 8

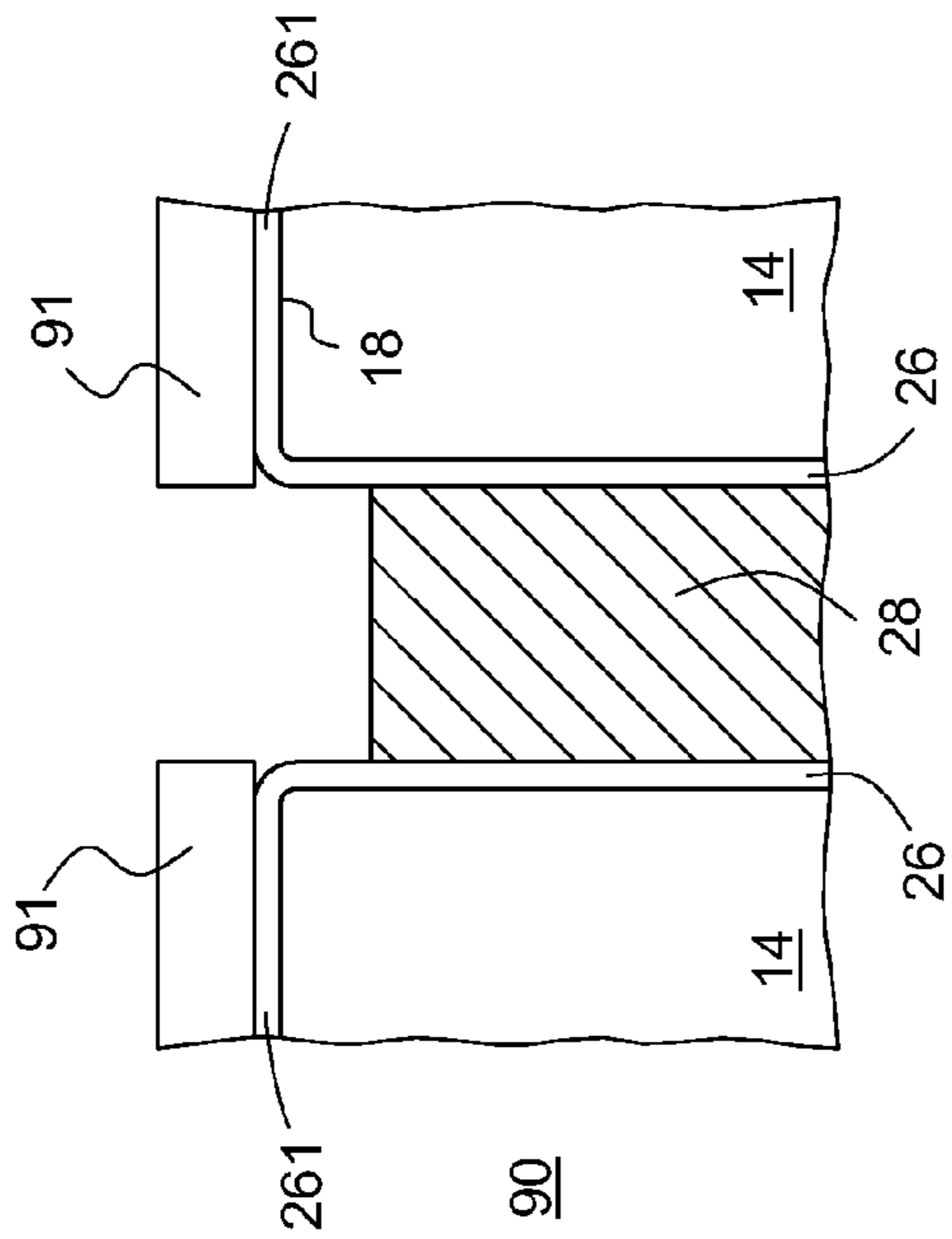


FIG. 9

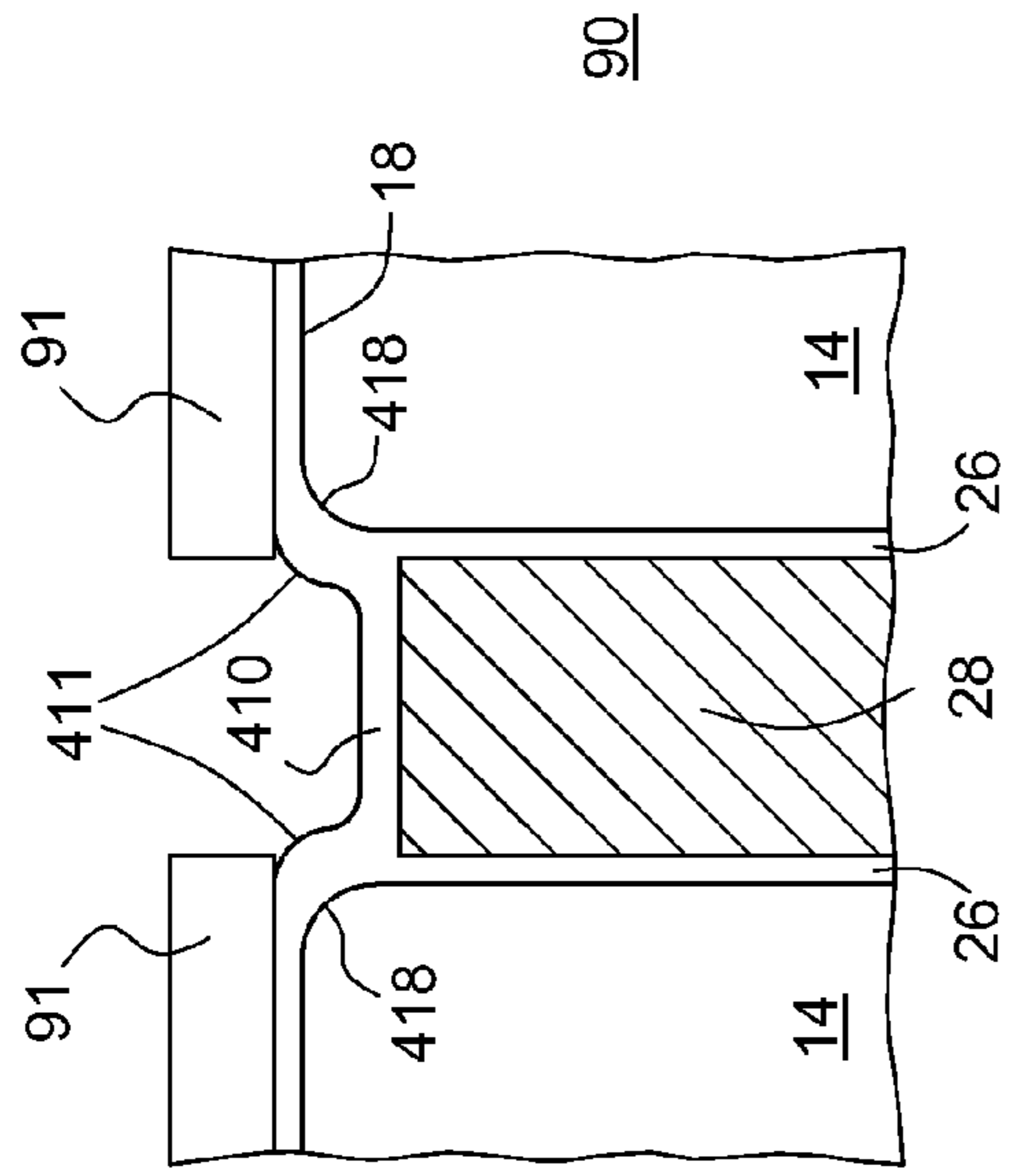


FIG. 10

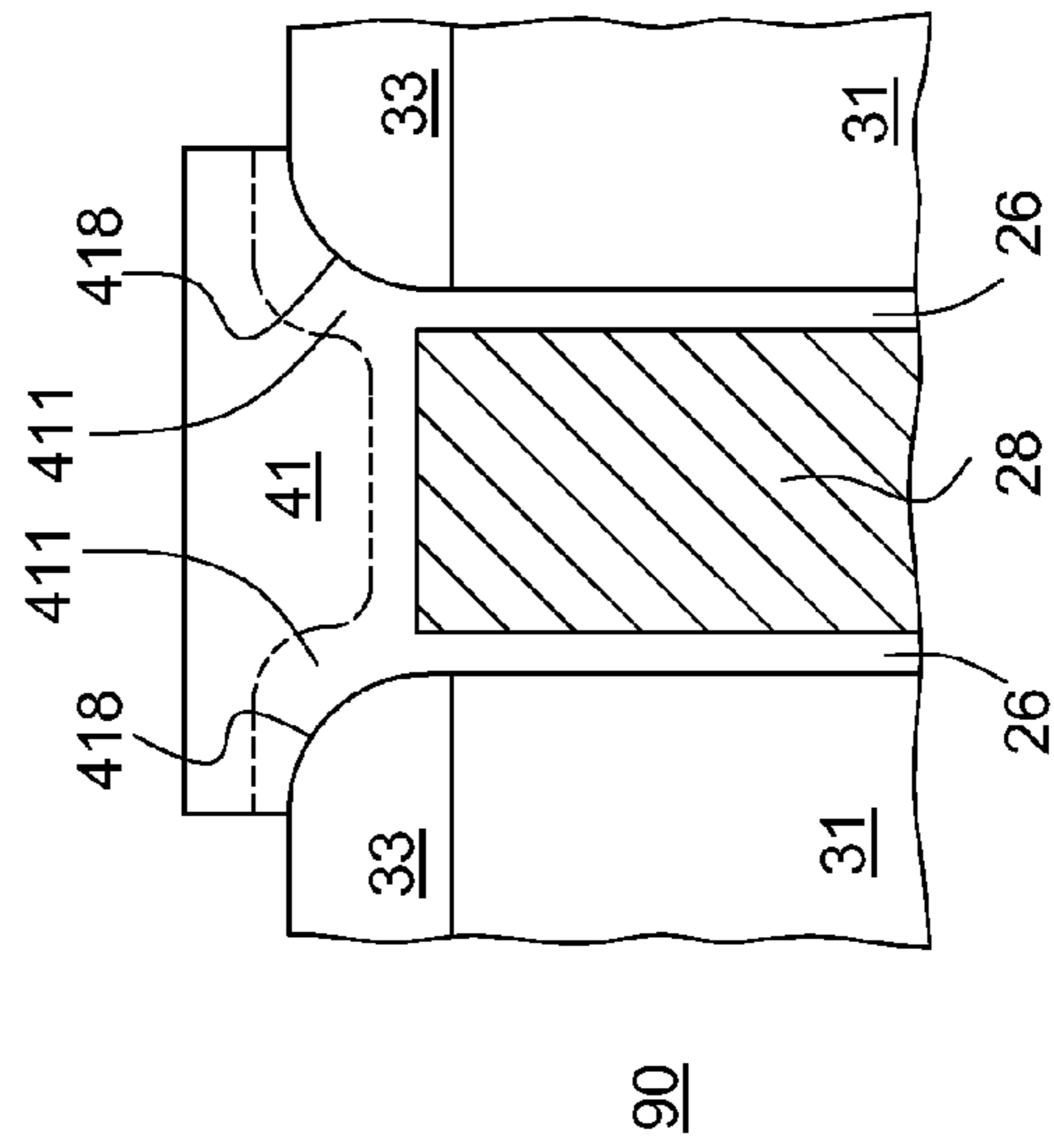


FIG. 11

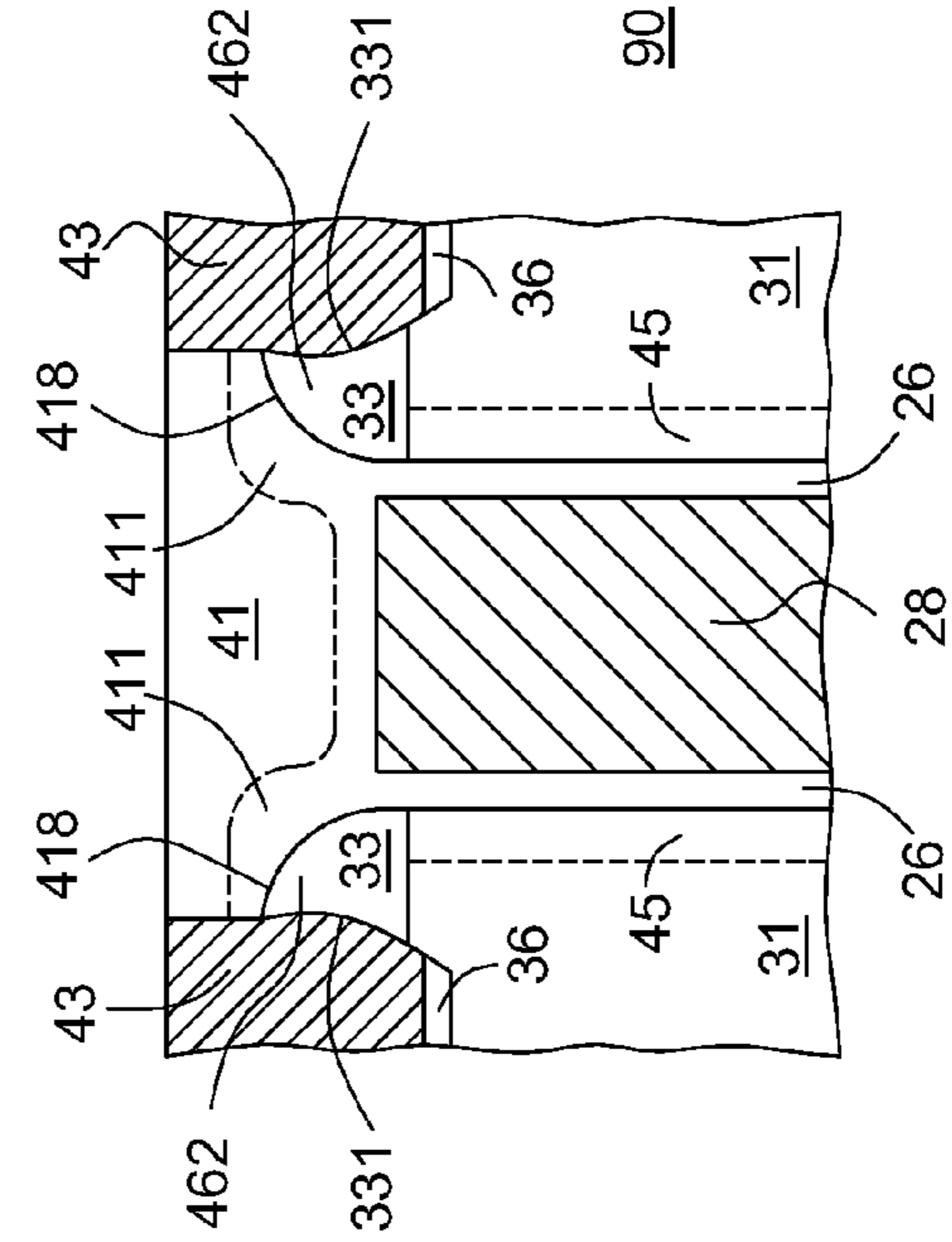


FIG. 12

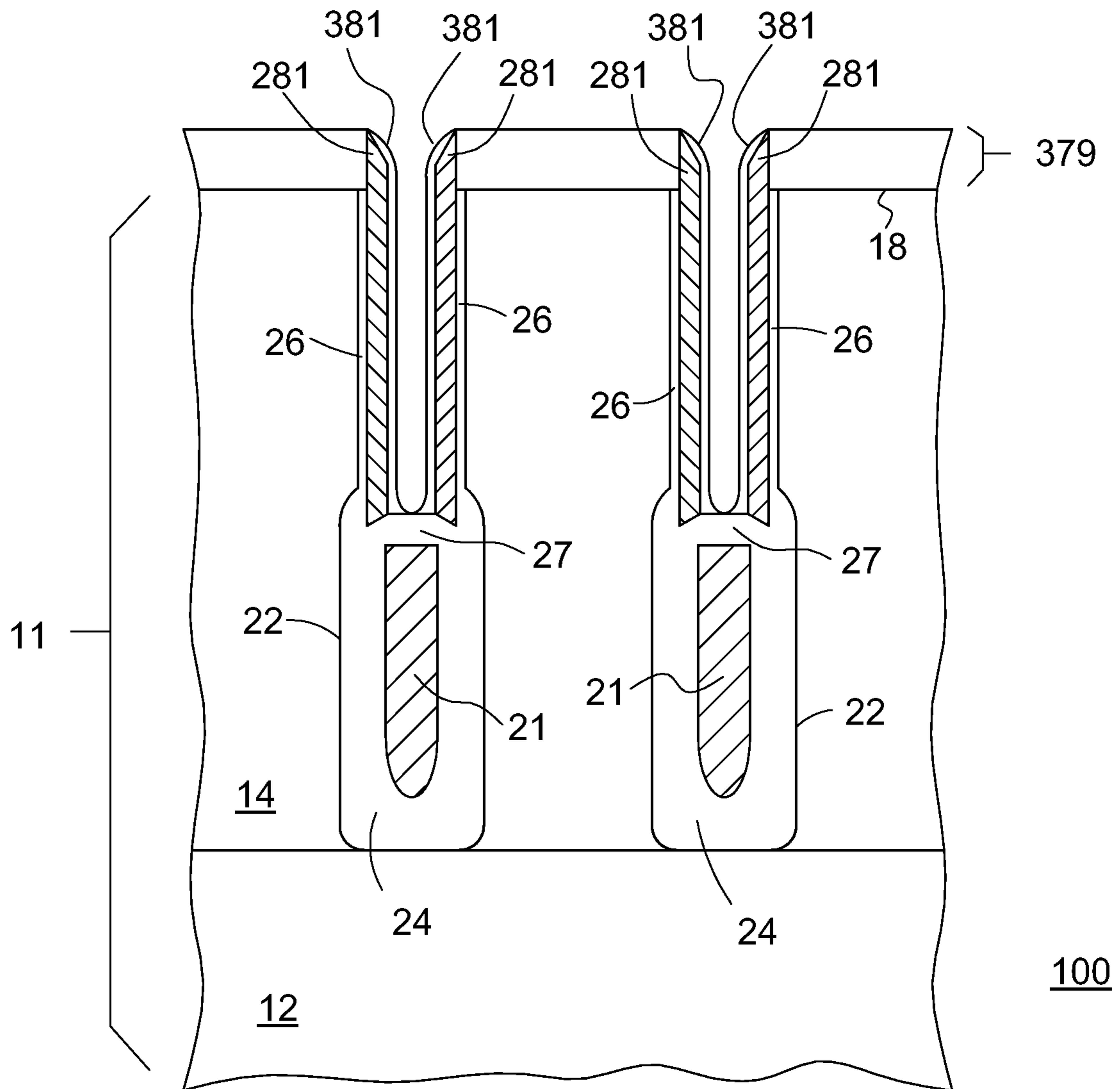


FIG. 13

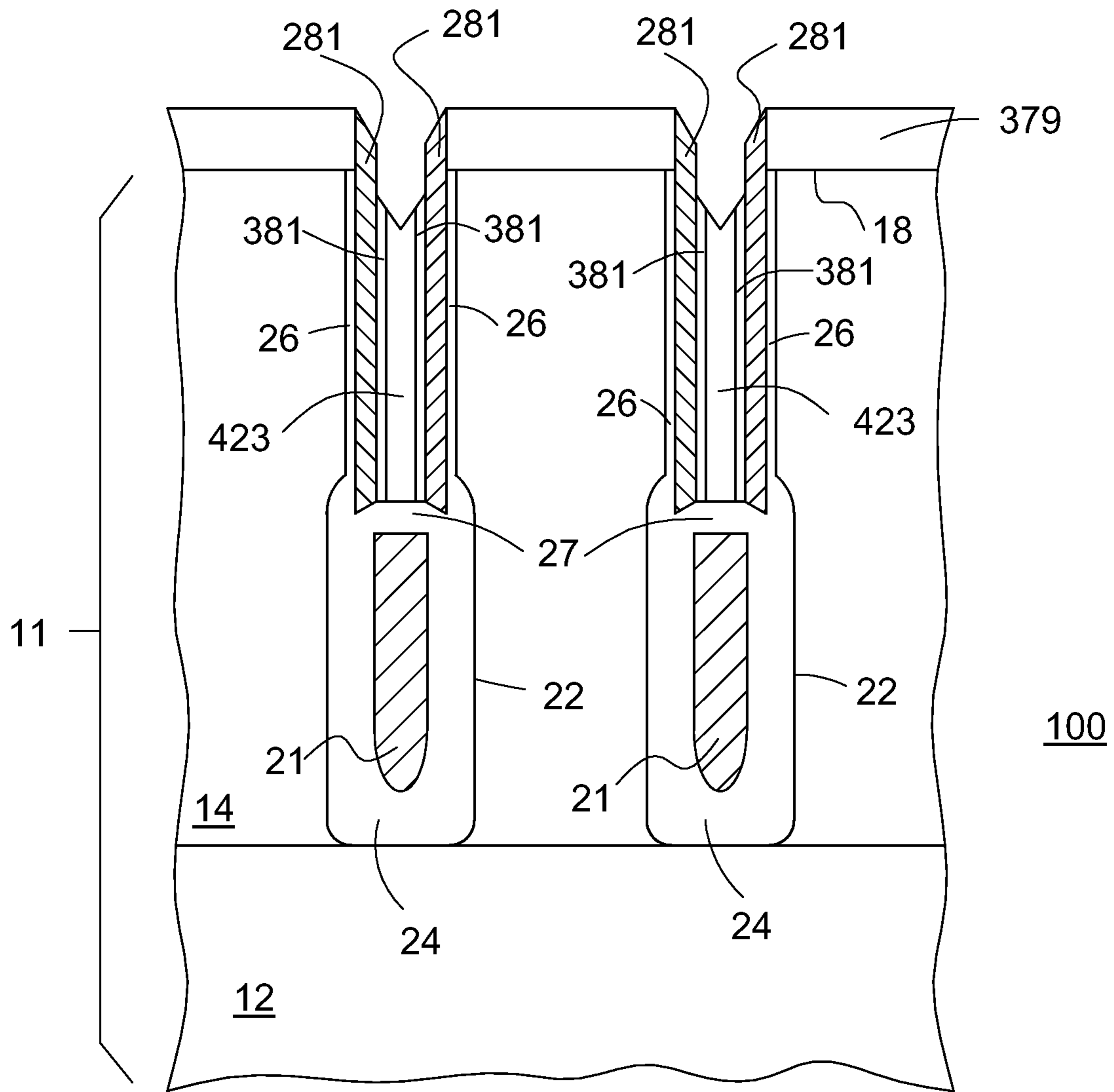


FIG. 14

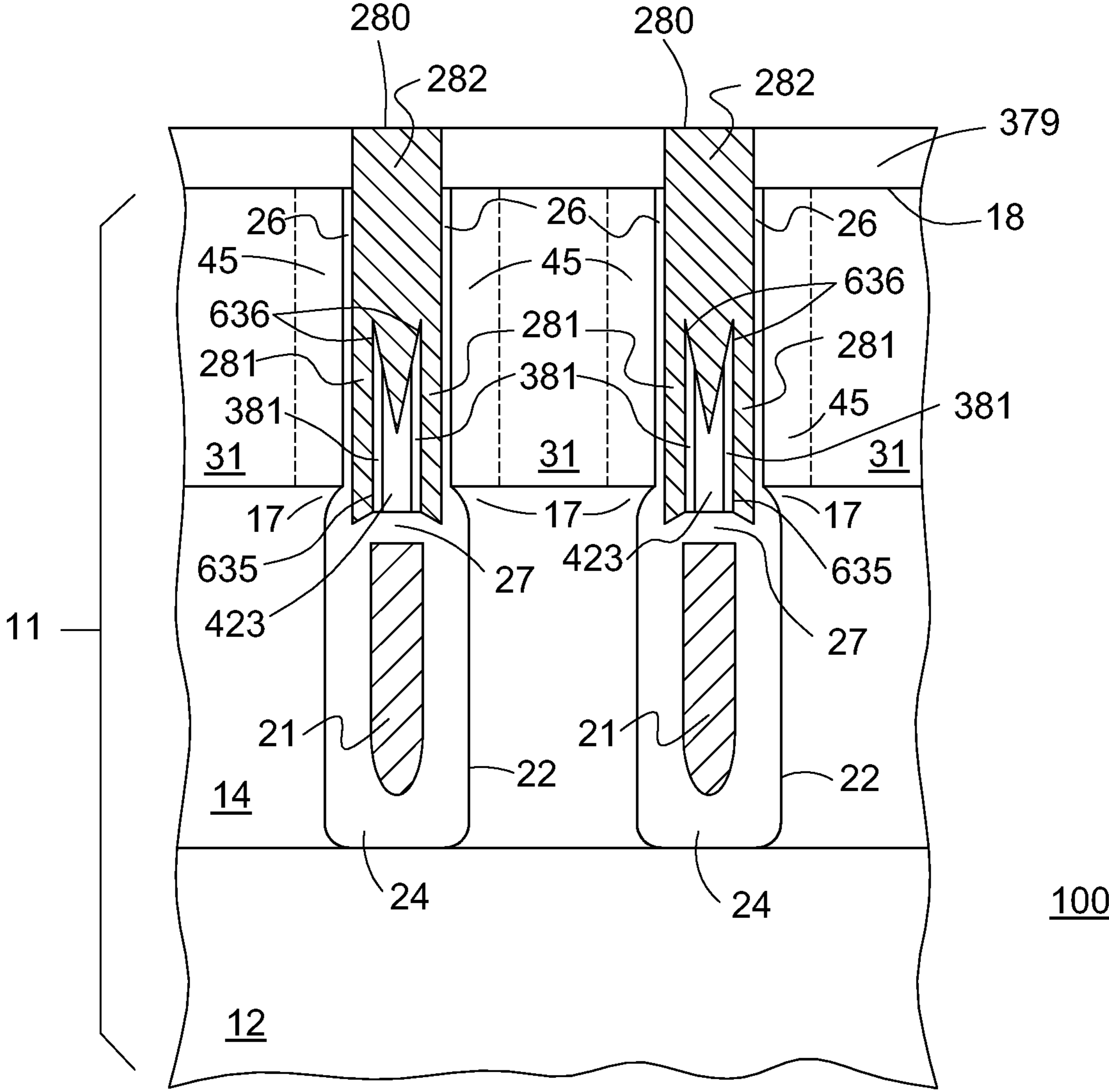


FIG. 15

SEMICONDUCTOR DEVICE WITH ENHANCED MOBILITY AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. application Ser. No. 13/159,255 entitled SEMICONDUCTOR DEVICE WITH ENHANCED MOBILITY AND METHOD filed Jun. 13, 2011 and issued as U.S. Pat. No. 8,466,513 on Jun. 18, 2013, which is incorporated herein by reference in its entirety to provide continuity of disclosure.

BACKGROUND OF THE INVENTION

This document relates generally to semiconductor devices, and more specifically to insulated gate structures and methods of formation.

Metal oxide field effect transistor (MOSFET) devices are used in many power switching applications such as dc-dc converters. In a typical MOSFET, a gate electrode provides turn-on and turn-off control with the application of an appropriate gate voltage. By way of example, in an n-type enhancement mode MOSFET, turn-on occurs when a conductive n-type inversion layer (i.e., channel region) is formed in a p-type body region in response to the application of a positive gate voltage, which exceeds an inherent threshold voltage. The inversion layer connects n-type source regions to n-type drain regions and allows for majority carrier conduction between these regions.

There is a class of MOSFET devices where the gate electrode is formed in a trench that extends downward from a major surface of a semiconductor material such as silicon. Current flow in this class of devices is primarily vertical and, as a result, device cells can be more densely packed. All else being equal, this increases the current carrying capability and reduces on-resistance of the device.

Achieving the lowest specific on-resistance (ohm-area) is an important goal of MOSFET device designers because it determines product cost and gross margins or profitability. In particular, the lower the specific on-resistance, the smaller the size of the MOSFET die or chip, which leads to lower costs in semiconductor materials and package structures.

Various methods are known for reducing on-resistance. Such methods include using advanced lithography and self-aligned structures to increase device density; adding recessed field plates or shield electrodes, which allow the use of higher drift region dopant concentrations; and using thinner and higher dopant concentration semiconductor substrates. Also, various packaging techniques have been implemented including certain mold compounds that provide stress induced carrier mobility enhancement. Additionally, in very low voltage advanced deep submicron CMOS devices (less than 5 volts) used in logic applications, enhanced carrier mobility has been achieved in planar gate structures by encapsulating the outer and upper surfaces of the gate electrode and portions of the outer surfaces of the source and drain regions with a stressed silicon-nitride film. Further, lattice mismatch semiconductor structures such as silicon-germanium devices have been proposed to enhance carrier mobility in power transistor devices, which in turn reduces on-resistance. However, such structures suffer from manufacturing drawbacks including lowered thermal budgets and reliability issues.

Accordingly, structures and methods of manufacture are needed to effectively further reduce on-resistance in power semiconductor devices such as vertical trench-gated semiconductor devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a partial cross-sectional view of a semiconductor structure in accordance with a first embodiment of the present invention;

FIG. 2 illustrates a partial cross-sectional view of a semiconductor structure in accordance with a second embodiment of the present invention;

FIG. 3 illustrates a partial cross-sectional view of a semiconductor structure in accordance with a third embodiment of the present invention;

FIG. 4 illustrates a partial cross-sectional view of a semiconductor structure in accordance with a fourth embodiment of the present invention;

FIG. 5 illustrates a partial cross-sectional view of a semiconductor structure in accordance with a fifth embodiment of the present invention;

FIGS. 6-8 illustrate partial cross-sectional views of a semiconductor device at various stages of fabrication in accordance with a method of the present invention;

FIGS. 9-12 illustrate partial cross-sectional views of another semiconductor device at various stages of fabrication in accordance with another method of the present invention; and

FIGS. 13-15 illustrate partial cross-sectional view of a further semiconductor device in accordance with the present invention at various stages of fabrication.

For simplicity and clarity of illustration, elements in the figures are not necessarily drawn to scale, and the same reference numbers in different figures denote generally the same elements. Additionally, descriptions and details of well-known steps and elements may be omitted for simplicity of the description. As used herein current-carrying electrode means an element of a device that carries current through the device such as a source or a drain of an MOS transistor or an emitter or a collector of a bipolar transistor or a cathode or anode of a diode, and a control electrode means an element of the device that controls current through the device such as a gate of a MOS transistor or a base of a bipolar transistor. Although the devices are explained herein as certain N-channel devices, a person of ordinary skill in the art will appreciate that P-channel devices and complementary devices are also possible in accordance with the present description. For clarity of the drawings, doped regions of device structures are illustrated as having generally straight-line edges and precise angular corners. However, those skilled in the art understand that due to the diffusion and activation of dopants, the edges of doped regions are generally not straight lines and the corners are not precise angles.

Further, the term "major surface" when used in conjunction with a semiconductor region or substrate means the surface of the semiconductor region or substrate that forms an interface with another material such as a dielectric or insulator, a conductor, a polycrystalline semiconductor. The major surface can have a topography that changes in the x, y and z directions.

In addition, structures of the present description may embody either a cellular base design (where the body regions are a plurality of distinct and separate cellular or stripe regions) or a single base design (where the body region is a single region formed in an elongated pattern, typically in a serpentine pattern or a central portion with connected appendages). However, one embodiment of the present description will be described as a cellular base design throughout the description for ease of understanding. It

should be understood that it is intended that the present disclosure encompass both a cellular base design and a single base design.

DETAILED DESCRIPTION OF THE DRAWINGS

In general, the present description pertains to a power semiconductor device. In one embodiment the power semiconductor device includes a trench gate electrode structure. In another embodiment the power semiconductor device can also include a shield electrode structure. Features that induce or propagate stress in predetermined locations of the power semiconductor device are formed in spaced relationship with trench gate electrode structure, the shield electrode structure, adjacent contact regions, regions there between, or combinations thereof. The features enhance carrier mobility, which in turn improves device performance parameters such as on-resistance.

FIG. 1 shows a partial cross-sectional view of a semiconductor device 10 or cell 10 having features or structures configured to create, propagate, induce, or generate stress within predetermined locations or regions of device 10. Device 10, as well as the other devices described herein, can comprise a plurality of such devices integrated as a discrete device and/or integrated with other functionality as a power integrated circuit.

In this embodiment, device 10 can be configured as a vertical power MOSFET structure, but it is understood that this description applies as well to lateral power MOSFET structures, insulated gate bipolar transistors (IGBT), MOS-gated thyristors, and the like. Device 10 includes a region of semiconductor material, semiconductor material, or semiconductor region 11, which can be for example, an n-type silicon substrate 12 having a resistivity in a range from about 0.001 ohm-cm to about 0.005 ohm-cm. Substrate 12 can be doped with phosphorous or arsenic. In the embodiment shown, substrate 12 provides a drain region, drain contact or a first current carrying contact for device 10.

A semiconductor layer, drift region, or extended drain region 14 can be formed in, on, or overlying substrate 12. In one embodiment, semiconductor layer 14 can be formed using semiconductor epitaxial growth techniques. Alternatively, semiconductor layer 14 can be formed using semiconductor doping and diffusion techniques. In an embodiment suitable for a 50 volt device, semiconductor layer 14 can be n-type with a dopant concentration of about 1.0×10^{16} atoms/cm³ and can have a thickness from about 3 microns to about 5 microns. The thickness and dopant concentration of semiconductor layer 14 can be increased or decreased depending on the desired drain-to-source breakdown voltage (BV_{DSS}) rating of device 10. In another embodiment, semiconductor layer 14 can comprise a plurality of epitaxial layers having different dopant concentrations and thicknesses. In another embodiment, semiconductor layer 14 can comprise a single epitaxial layer having a graded dopant profile. In an alternate embodiment, the conductivity type of substrate 12 can be switched to be opposite to the conductivity type of semiconductor layer 14 to form, for example, an IGBT embodiment.

Device 10 also includes a body, base, or doped region or regions 31 extending from a major surface 18 of semiconductor material 11. Body regions 31 can have a conductivity type that is opposite to the conductivity type of semiconductor layer 14. In this example, body regions 31 are p-type conductivity. Body regions 31 have a dopant concentration configured for forming inversion layers that operate as conduction channels or channel regions 45 of device 10. Body regions 31 can extend from major surface 18 to a depth, for example,

from about 0.5 microns to about 2.0 microns. In this embodiment, n-type source regions, current conducting regions, or current carrying regions 33 are formed within, in, or overlying body regions 31 and can extend from major surface 18 to a depth, for example, from about 0.1 microns to about 0.5 microns. A p-type body contact, enhancement region, or contact region 36 can be formed in body regions 31, and typically is configured to provide a lower contact resistance to body regions 31.

Device 10 can further include trench control, trench gate, or trench structures 19, which typically extend in a substantially vertical direction from major surface 18. Alternatively, trench control structures 19 or portions thereof can have a tapered shape. Trench structures 19 include trenches 22, which can be formed within region of semiconductor material 11. For example, trenches 22 can have a depth from about 1.5 microns to about 2.5 microns or shallower or deeper. In one embodiment, trenches 22 can extend all the way through semiconductor layer 14 into substrate 12. In another embodiment, one or more trenches 22 can terminate within semiconductor layer 14.

In this embodiment, dielectric layers, insulator layers, field insulator layers or regions 24 are formed on lower portions of trenches 22. In one embodiment, insulator layers 24 can be silicon oxide, and can have a thickness from about 0.1 microns to about 0.2 microns. Additionally, the thickness of layer 24 can be increased or decreased, depending on the desired drain-to-source breakdown voltage (BV_{DSS}). Shield electrodes 21 are formed adjacent insulator layers 24 typically in substantially centrally located lower portions of trenches 22. In one embodiment, shield electrodes 21 comprise doped polycrystalline semiconductor material. In other embodiments, shield electrodes 21 can comprise other conductive materials.

Dielectric or insulator layers 26 typically are formed along upper sidewall portions of trenches 22, and can be configured as gate dielectric regions or layers. By way of example, insulator layers 26 typically comprise oxide, nitride, tantalum pentoxide, titanium dioxide, barium strontium titanate, hafnium oxide, combinations thereof, or the like. In one embodiment, insulator layers 26 comprise silicon oxide and can have a thickness from about 0.01 microns to about 0.1 microns. In one embodiment, insulator layers 24 can be thicker than insulator layers 26. Dielectric or insulator layers 27 typically are formed overlying shield electrodes 21, and in one embodiment, insulator layers 27 can have a thickness that is between or greater than the thickness of insulator layers 24 and insulator layers 26. In one embodiment, insulator layers 27 can have a thickness greater than the thickness of insulator layer 26, which can improve oxide breakdown voltage performance. In one embodiment, insulator layers 27 can have a thickness between about 0.1 microns to about 0.3 microns.

In this embodiment, trench structures 19 typically include control electrodes or gate electrodes 28, which are formed adjacent insulator layers 26 and 27. In one embodiment, gate electrodes 28 can comprise doped polycrystalline semiconductor material such as polysilicon doped with an n-type dopant.

Device 10 further includes one or more features such as structures or stressed films 23, 231, 232, and/or 233, which are configured to create, propagate, induce, or generate stress within predetermined locations or regions of device 10. Such predetermined locations can include channel regions 45 and/or drift regions 17. By way of example, structures 23, 231, 232, and 233 comprise a stressed film or stress inducing film such as dielectric films including a silicon nitride, a silicon oxynitride, or a silicon oxide, combinations thereof, or the

like. Alternatively, structures **23**, **231**, **232**, and **233** can comprise conductive films such as silicides or metals. In further embodiments, such structures can comprise undoped polysilicon, semi-insulating polysilicon (“SIPOS”), or the like.

In one embodiment, structures **23** can be formed within gate electrodes **28** and in proximity to channel regions **45**. In one embodiment, structures **23** can be substantially centrally located within gate electrodes **28**. In one embodiment, structures **23** can be placed less than or equal to approximately 0.2 microns from channel regions **45**. By way of example, structure **23** typically is configured to generate stress such as tensile stress in proximity to channel regions **45** within region of semiconductor material **11** when device **10** comprises an n-channel device. Stated another way, structure **23** is under compressive stress to generate tensile stress in proximity to channel regions **45** within region of semiconductor material **11**. When device **10** comprises a p-channel device, structure **23** is under tensile stress in order to generate a compressive stress in proximity to channel regions **45**.

Structures **231** can be formed overlying gate electrodes **28** or in proximity to upper surfaces of gate electrodes **28**. Structures **231** are configured to generate stress such as tensile stress in proximity to source ends of channel regions **45**. Stated another way, structures **231** can be under compressive stress to generate tensile stress in proximity to the source ends of channel regions **45** within region of semiconductor material **11**. When device **10** comprises a p-channel device, structures **231** can be under tensile stress in order to generate a compressive stress in proximity to channel regions **45**.

Structures **232** can be formed overlying shield electrodes **21**. Structures **232** are configured, for example, to generate stress such as tensile stress in proximity to drain ends of channels **45** and in proximity to drift regions **17**. Stated another way, structures **232** can be under compressive stress to generate tensile stress in proximity to the drain ends of channel regions **45** and in proximity to drift regions **17** within region of semiconductor material **11**. When device **10** comprises a p-channel device, structures **232** can be under tensile stress in order to generate a compressive stress in proximity to the drain ends of channel regions **45** and in proximity to drift regions **17**.

Structures **233** can be formed within shield electrodes **21**. Structures **233** are configured, for example, to generate stress such as tensile stress in proximity the drain ends of channel regions **45** and in proximity to drift regions **17**. Stated another way, structures **233** can be under compressive stress to generate tensile stress in proximity to the drain ends of channel regions **45** and in proximity to drift regions **17** within region of semiconductor material **11**. When device **10** comprises a p-channel device, structures **233** can be under tensile stress in order to generate a compressive stress in proximity to the drain ends of channel regions **45** and in proximity to drift regions **17**.

It is understood that one or more of structures **23**, **231**, **232**, and **233** can be used with device **10**. In addition, structures **23**, **231**, **232**, and **233** can comprise stripe-like shapes. In one embodiment, structures **23** and **233** can be rectangular in cross-section with the longest sides running substantially parallel to channel regions **45** and drift regions **17** respectively. In other embodiments, the longest sides can run substantially perpendicular to channel regions **45**. In one embodiment, structures **23** can have a length that is equal to or greater than the length of channels **45**. In one embodiment, structures **23** can have a length that is less than the length of channels **45**.

In accordance with the present embodiment, structures **23**, **231**, **232**, and **233** increase carrier mobility, which in turn reduces on-resistance for device **10**. By way of example,

simulation results show that such structures can reduce on-resistance by at least 5% to 30%. One benefit of structures **23**, **231**, **232** or/and **233** is that these structures can facilitate a device active area shrink, which can mean more functional devices in a given area or a reduction in the actual chip size. Simulations of these structures suggest active area shrinks of about 5% to 30%.

An interlayer dielectric (ILD), dielectric, or insulator layer **41** is formed overlying major surface **18** and above trench structures **19**. In one embodiment, dielectric layer **41** comprises a silicon oxide and can have a thickness from about 0.4 microns to about 1.0 microns. In one embodiment, dielectric layer **41** comprises a deposited silicon oxide doped with phosphorous or boron and phosphorous. In one embodiment, dielectric layer **41** can be planarized to provide a more uniform surface topography, which improves manufacturability.

Conductive regions or plugs **43** are formed through openings, contact trenches, or vias in dielectric layer **41** and portions of semiconductor layer **14** to provide for electrical contact to source regions **33** and body regions **31** through contact regions **36**. In one embodiment, conductive regions **43** are conductive plugs or plug structures. In one embodiment, conductive regions **43** comprise a conductive barrier structure or liner plus a conductive fill material. In one embodiment, the barrier structure includes a metal/metal-nitride configuration such as titanium/titanium-nitride or the like. In another embodiment, the barrier structure can further include a metal-silicide structure. In one embodiment, the conductive fill material includes tungsten. In one embodiment, conductive regions **43** are planarized to provide a more uniform surface topography.

A conductive layer **44** can be formed overlying major surface **18** and a conductive layer **46** can be formed overlying a surface of semiconductor material **11** opposite major surface **18**. Conductive layers **44** and **46** typically are configured to provide electrical connection between the individual device components of device **10** and a next level of assembly. In one embodiment, conductive layer **44** is titanium/titanium-nitride/aluminum-copper or the like and is configured as a source electrode or terminal. In one embodiment, conductive layer **46** is a solderable metal structure such as titanium-nickel-silver, chromium-nickel-gold, or the like and is configured as a drain electrode or terminal. In one embodiment, a further passivation layer (not shown) is formed overlying conductive layer **44**. In one embodiment, shield electrodes **21** are connected (in another plane) to conductive layer **44** so that shield electrodes **21** are configured to be at the same potential as source regions **33** when device **10** is in use. In another embodiment, shield electrodes **21** can be configured to be independently biased. In a further embodiment, a portion of shield electrodes **21** can be electrically connected to gate electrodes **28**.

In one embodiment, the operation of device **10** proceeds as follows. Assume that source electrode (or input terminal) **44** and shield electrodes **21** are operating at a potential V_S of zero volts, gate electrodes **28** receive a control voltage V_G of 4.5 volts, which is greater than the conduction threshold of device **10**, and drain electrode (or output terminal) **46** operates at a drain potential V_D of less than 2.0 volts. The values of V_G and V_S cause body region **31** adjacent to gate electrodes **28** to invert to form channels **45**, which electrically connect source regions **33** to semiconductor layer **14**. A device current I_{DS} flows from drain electrode **46** and is routed through semiconductor layer **14**, channels **45**, and source regions **33** to source electrode **44**. In one embodiment, I_{DS} is on the order of 10.0 amperes. In accordance with the present embodiment, structures **23**, **231**, **232**, and/or **233** propagate stress into region of

semiconductor material **11**, which increases carrier mobility within channels **45** and/or drift regions **17**. This in turn reduces on-resistance for device **10**. To switch device **10** to the off state, a control voltage V_G of less than the conduction threshold of device **10** is applied to gate electrodes **28** (e.g., $V_G < 2.5$ volts). This removes channels **45** and I_{DS} no longer flows through device **10**.

FIG. **2** shows a partial cross-sectional view of a semiconductor device **20** in accordance with a second embodiment. Device **20** is similar to device **10**, but includes alternative features or structures configured to create, propagate, induce, or generate stress within predetermined locations or regions of device **20**. Specifically, device **20** can include one more structures **32**, **322**, and **323**, which can comprise a stressed film or stress inducing film such as a dielectric film including a silicon nitride, a silicon oxynitride, or a silicon oxide, combinations thereof, or the like. Alternatively, structures **32**, **322**, and **323** can comprise conductive films such as silicides or metals. Further, such structure can comprise undoped polysilicon or SIPOS. In one embodiment, structures **32**, **322**, and **323** are placed within less than or equal to about 0.2 microns of the region where it is desired the stress be induced.

In this embodiment, structures **32** can be formed within gate electrode **28** to induce stress such as tensile stress within channel regions **45**. Stated another way, structures **32** can be under compressive stress to generate tensile stress in proximity to channel regions **45** within region of semiconductor material **11** when device **20** comprises an n-channel device. When device **20** comprises a p-channel device, structures **32** can be under tensile stress in order to generate a compressive stress in proximity to channel regions **45**. By way of example, structures **32** can be a plurality of spaced-apart stripe-like shapes having rectangular cross-sections with the longer sides placed approximately parallel to channel regions **45**. In other embodiments, the longer sides can be placed approximately perpendicular to channel regions **45**. It is understood that structures **32** can comprise one or more structures.

Structures **322** can be placed, for example, at lower and outer tip portions of gate electrode **28**. Structures **322** are configured or placed to induce or propagate stress such as tensile stress within region of semiconductor material **11** (e.g., semiconductor layer **14**) in proximity to the drain-end of channel regions **45** and drift regions **17**. Stated another way, structures **322** can be under compressive stress to generate tensile stress in proximity to channel regions **45** and in proximity to drift regions **17** when device **20** comprises an n-channel device. When device **20** comprises a p-channel device, structures **322** can be under tensile stress in order to generate a compressive stress in proximity to channel regions **45** and in proximity to drift regions **17**.

Structures **323** can be placed, for example, within shield electrodes **21**, and can be a pair of spaced-apart stripe-like shapes having rectangular cross-sections with the longer sides placed approximately perpendicular to the direction of channel regions **45**. In another embodiment, the longer sides of structures **323** can be placed approximately parallel to the direction of channel regions **45**. Structures **322** are configured or placed to induce or propagate stress such as tensile stress within drift regions **17**. Stated another way, structures **323** can be under compressive stress to generate tensile stress in proximity to drift regions **17** when device **20** comprises an n-channel device. When device **20** comprises a p-channel device, structures **323** can be under tensile stress in order to generate a compressive stress in proximity to drift regions **17**. In accordance with the present embodiment, structures **32**, **322**, and **323** increase carrier mobility in the regions under stress, which in turn reduces on-resistance for device **20**.

FIG. **3** is a partial cross-sectional view of a device **30** in accordance with another embodiment. Device **30** is similar to devices **10** and **20**. Device **30** further includes structures **334** that can be placed within, adjacent or below conductive structures **43**, and are configured or placed to induce stress in proximity to source-ends of channels **45**. Structures **334** comprise a stressed film or stress inducing film such as dielectric films including a silicon nitride, a silicon oxynitride, or a silicon oxide, or undoped polysilicon, SIPOS, or combinations thereof, or the like. Structures **334** can be used by themselves or together with any of the stress-inducing structures described herein. When device **30** comprises an n-channel device, structures **334** can be under compressive stress to generate tensile stress in proximity to the source ends of channel regions **45**. When device **30** comprises a p-channel device, structures **334** can be under tensile stress to generate compressive stress in proximity to the source ends of channel regions **45**.

FIG. **4** is a partial cross-sectional view of a device **40** in accordance with a further embodiment. Device **40** is similar to devices **10** and **20**, and further includes composite or multi-layered structures **420** and **430** for inducing or propagating stress within various segments of device **40**. For example, when device **40** is an n-channel device, structures **420** and **430** can be under compressive stress to induce a tensile stress within the various segments. Alternatively, when device **40** comprises a p-channel device, structures **420** and **430** can be under tensile stress to induce a compressive stress within the various segments.

Composite structure **420** can include multiple layers including different materials. For example, composite structure **420** is formed or placed within gate electrode **28** to induce stress in proximity to or within channel regions **45**. In one embodiment, composite structure **420** can include a region **422** of one material sandwiched or placed between a pair of regions **421** of different material. For example, region **422** can comprise an oxide, and regions **421** can comprise a nitride or a conductive material such as a silicide. Alternatively, region **422** can comprise a nitride and regions **421** can comprise an oxide or a conductive material such as a silicide. In an optional embodiment, device **40** can include a composite structure **430**, which includes a region **432** of one material sandwiched or placed between a pair of regions **431** of a different material. For example, region **432** can comprise an oxide, and regions **431** can comprise a nitride or a conductive material such as a silicide. Alternatively, region **432** can comprise a nitride and regions **431** can comprise an oxide or a conductive material such as a silicide. It is understood that structures **420** and **430** can be rotated. For example, they can be rotated 90 degrees from what is shown in FIG. **4**.

FIG. **5** is a partial cross-section view of a device **50** in accordance with a still further embodiment. Device **50** is similar to devices **10** and **20**. Device **50** includes structures **501** and optionally **511** for inducing stress within specific or predetermined locations or parts of device **50**. For example, when device **50** comprises an n-channel device, structures **501** and **511** can be under compressive stress to induce a tensile stress within the predetermined locations or parts. Alternatively, when device **50** comprises a p-channel device, structures **501** and **511** can be under tensile stress to induce a compressive stress within the specific locations or parts. In this embodiment, structure **501** can be a "U" like shape or horseshoe like shape with a base portion **502** and side portions **503** extending away from base portion **502**. Base portion **502** can be thicker than side portions **503**. Structure **501** comprises a stressed film or stress inducing material such as dielectric films including a silicon nitride, a silicon oxyni-

tride, or a silicon oxide, or undoped polysilicon, or SIPOS, or combinations thereof, or the like. Alternatively, structure **501** can comprise conductive films such as silicides or metals. Structure **501** is placed within gate electrode **28** for inducing stress, for example, in channel regions **45**. In one embodiment, structure **501** can be inverted or rotated 180 degrees from the orientation shown in FIG. **5**. One further advantage of structure **511** is that it can reduce the capacitance between gate electrode **28** and shield electrode **21**.

Structure **511** is a stripe-like structure that bisects or passes through shield electrode **21**. Structure **511** comprises materials similar to those materials described for structures **233** and **323**. Structure **511** can be placed within shield electrode **21** for inducing stress, for example in drift regions **17**. It is understood that structure **501** can be used within shield electrode **21** as well.

FIGS. **6-8** are partial cross-sectional views of a device **60** at various steps of fabrication, which illustrate a method of forming regions **362** within source regions **33**, which are configured to induce stress within the source ends of channels **45**. FIG. **6** shows device **60** after a contact opening **61** is formed through ILD layer **41**, portions of source regions **33** and extends into body region **31**. Next, a thermal oxide process can be used to form an insulating layer along exposed portions of the source regions **33** and body region **31** as shown in FIG. **7**. In one embodiment, a wet oxide formed using a temperature from about 825 degrees Celsius to about 925 degrees Celsius and a time from about 3 minutes to about 10 minutes. With this process, the insulating layer is formed having a thicker portion **62** in proximity to source regions **33** and a thinner portion **63** in proximity to body region **31**. Thicker portions **62** provide an offset for incorporating dopant into body region **31** to form enhancement region **36**. The insulating layer can then subsequently removed and conductive region **43** formed within contact opening **61** as shown in FIG. **8**. The above described process for forming the insulating layer having thicker portions **62** was found to form regions **362** of elevated stress that beneficially propagates to channel regions **45**. Specifically, regions **362** were found to reduce on-resistance by about 3% to about 6%.

FIGS. **9-12** are partial cross-sectional views of a device **90** at various steps of fabrication to illustrate a method of forming regions **462** within source regions **33**, which induce stress within or in proximity to the source ends of channels **45**. FIG. **9** shows device **90** after gate electrode **28** has been formed. For example, when gate electrode **28** comprises doped polysilicon, a silicon recess etch is used to etch the polysilicon below major surface **18** as shown in FIG. **9**. For this step, a hard mask layer **91** can be used while forming gate electrode **28**. In one embodiment, hard mask layer **91** can be non-oxidizing film such a silicon nitride, which is formed overlying a dielectric layer **261**. In this embodiment, dielectric layer **261** can be a silicon oxide.

In a subsequent step and in accordance with this embodiment, the upper surface of gate electrode **28** and the upper surfaces of the trench are exposed to a wet oxidation process at a temperature between 850 degrees Celsius and 950 degrees Celsius to form dielectric film **410**. Dielectric film **410** can have a thickness of about 0.075 microns to about 0.35 microns or more. Hard mask layer **91** causes dielectric film **410** to form laterally below hard mask **91** in a "birds-beak" like manner. That is, dielectric film **410** includes portions **411** that overhang portions **418** of major surface **18**.

In subsequent steps, body regions **31**, source regions **33** and ILD layer **41** can be formed as shown in FIG. **11**. In one embodiment, ILD layer **41** can be formed self-aligned to hard mask layer **91**. In one embodiment, ILD layer **41** can be

formed and then planarized using hard mask layer **91** as a stop-layer. Hard mask layer **91** can then be removed. Further, in accordance with the present embodiment, an etch such as a silicon etch is used to etch through source regions **33** to body regions **31** for forming body contact regions **36** as shown in FIG. **12**. Portions **411** of dielectric film **410** shown in FIG. **10** are configured to overhang and block or mask the silicon etch, which forms source region **33** into a narrowed or slit-like shape. In one embodiment, a sloped silicon etch is used to form sloped sidewalls **331** of source regions **33** as shown in FIG. **12**. In subsequent steps, conductive layers or plugs **43** can be formed. It was found that the wet oxidation process used to form dielectric layer **410** including portion **411** together with the sloped silicon etch resulted in the generation of regions **462** of elevated stress within source regions **33**. Regions **462** of elevated stress beneficially propagate to channel regions **45**, and were found using simulation results to reduce on-resistance by as much as 20%.

FIGS. **13-15** are partial cross-sectional views of a device **100** at early stages of fabrication. Device **100** is fabricated, for example, to include a feature **423**, which is configured to create, propagate, induce, or generate stress within predetermined locations or regions of device **100**. FIG. **13** shows device **100** at an intermediate step with a dielectric stack **379** formed overlying major surface **18** of region of semiconductor material **11**. At this intermediate step, insulated shield electrodes **21** have been formed within lower portions of trenches **22**. After insulator layers **27** have been formed, a polycrystalline semiconductor layer can be deposited overlying or adjacent dielectric stack **379**, insulator layers **26** and insulator layer **27**. In one embodiment, the polycrystalline semiconductor layer can be polysilicon that can be doped in-situ or after it is deposited. An anisotropic etch can then used to form spacer layers **281** adjacent insulator layers **26** as shown in FIG. **13**.

In one embodiment, layers **381** can be formed adjacent spacer layers **281**. In one embodiment, layers **381** are configured for inducing stress within specific or predetermined locations or parts of device **100**. For example, when device **100** comprises an n-channel device, layers **381** can be under compressive stress to induce a tensile stress within the predetermined locations or parts. Alternatively, when device **100** comprises a p-channel device, layers **381** can be under tensile stress to induce a compressive stress within the specific locations or parts. Layers **381** can comprise one or materials such as dielectric films including a silicon nitride, a silicon oxynitride, or a silicon oxide, or undoped polysilicon, or SIPOS, or combinations thereof, or the like. In one embodiment, layers **381** can comprise a silicide material. In one embodiment, layers **381** can be omitted.

In a subsequent step, a film or layer that induces stress within semiconductor layer **14** of device **100** is formed adjacent layers **381** and dielectric stack **379**, and then etched back to form structures **423** as shown in FIG. **14**. If layers **381** are used, layers **381** can also be etched back with structure **423**. In one embodiment, structures **423** are configured for inducing stress within specific or predetermined locations or parts of device **100**. For example, when device **100** comprises an n-channel device, structures **423** can be under compressive stress to induce a tensile stress within the predetermined locations or parts. Alternatively, when device **100** comprises a p-channel device, structures **423** can be under tensile stress to induce a compressive stress within the specific locations or parts. In one embodiment, structures **423** can comprise one or more materials such as dielectric films including a silicon nitride, a silicon oxynitride, or a silicon oxide, or undoped

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polysilicon, or SIPOS, or combinations thereof, or the like. Alternatively, structures 423 can comprise conductive films such as silicides or metals.

In a subsequent step, structures 423 (and layers 381) can be further etched back to a predetermined location within trenches 22 as shown in FIG. 15. In a subsequent step, conductive portions or regions 282 are formed overlying structure 423, and together with spacer layers 281, conductive portions 282 form gate electrodes 280. Body regions 31 are shown formed within region of semiconductor material 11. In this embodiment, structures 381 or/and 423 can be configured or placed to induce stress within channel regions 45 and upper portions of drift region 17. In one embodiment, structures 423 and layers 381 form a feature for inducing stress that includes a base portion 635 in proximity to the drain end of channel regions 45 and a pair of projections or pointed projections 636 that extend away from the base portion towards major surface 18.

From all of the foregoing, one skilled in the art can determine that according to one embodiment a semiconductor device comprises a region of semiconductor material having a major surface. A trench control structure is formed in the region of semiconductor material including a gate dielectric layer formed overlying sidewall surfaces of the trench control structure and a gate electrode (for example, element 28) comprising a first conductive material formed overlying the gate dielectric layer. A body region is formed within the region of semiconductor material and adjacent the trench control structure, where the trench control structure is configured to form a channel region (for example, element 45) within the body region. A source region (for example, element 33) is formed within the body region has a first side adjacent the trench control structure and a second side opposite to the first side. A first feature (for example, element 23, 32, 322, 421, 422, 423, 501) comprising a material other than the first conductive material is formed within the gate electrode, where the first feature is configured to induce stress within portions of the channel region.

Those skilled in the art will also appreciate that according to another embodiment, the trench control structure in the device described in the preceding paragraph further includes a shield electrode (for example, element 21) below the gate electrode, where the shield electrode is separated from the region of semiconductor material by a dielectric layer, where a second feature (for example, element 233, 323, 431, 432, 511) is formed within the shield electrode, where the second feature is configured to induce stress within a drift region of the semiconductor device.

Those skilled in the art will also appreciate that according to yet another embodiment, an insulating gate field effect transistor structure having enhanced mobility comprises a region of semiconductor material having a first conductivity type, a first major surface, and a second major surface opposing the first major surface, where the region of semiconductor material at the second major surface is configured as a drain region. A trench structure is formed within the region of semiconductor material comprising a shield electrode (for example, element 21) formed in a lower portion of a trench, where the shield electrode is separated from the region of semiconductor material by a first dielectric layer; a gate electrode (for example, element 28) formed in an upper portion of the trench, wherein the gate electrode is separated from the region of semiconductor material by a second dielectric layer and separated from the shield electrode by a third dielectric layer. A body region having a second conductivity type opposite to the first conductivity type is formed in the region of semiconductor material and adjacent to the trench structure,

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where the gate electrode is configured to form a channel region (for example, element 45) within the body region. A source region (for example, element 33) of the first conductivity type is formed in spaced relationship with the body region having a first side adjacent to the trench structure and a second side opposite to the first side. A first region (for example, element 23, 32, 322, 421, 422, 423, 501) is formed within the gate electrode and comprising a material that propagates stress within the region of semiconductor material adjacent to the trench control structure to provide the enhanced mobility.

Those skilled in the art will also appreciate that according to an additional embodiment, a method for forming a semiconductor device comprises steps of providing a region of semiconductor material having a major surface, and forming a trench control structure in the region of semiconductor material including a gate dielectric layer overlying sidewall surfaces of the trench control structure, a gate electrode (for example, element 28) comprising a first conductive material overlying the gate dielectric layer, and a first feature (for example, element 23, 32, 322, 421, 422, 423, 501) comprising a material other than the first conductive material within the gate electrode. The method includes forming a body region within the region of semiconductor material and adjacent the trench control structure, where the trench control structure is configured to form a channel region (for example, element 45) within the body region. The method includes forming a source region within the body region having a first side adjacent the trench control structure and a second side opposite to the first side, where the first feature is configured to induce stress within portions of the channel region.

Those skilled in the art will also appreciate that according to a further embodiment, a method for forming a semiconductor device having enhanced mobility comprises the steps of providing a semiconductor material having a major surface and a drift region, where the device is configured as a vertical power semiconductor device. The method includes forming a trench control structure in the region of semiconductor material including a gate dielectric layer overlying sidewall surfaces of the trench control structure and a gate electrode comprising a first conductive material overlying the gate dielectric layer. The method includes forming a body region within the region of semiconductor material and adjacent the trench control structure, where the trench control structure is configured to form a channel region (for example, element 45) within the body region, and forming a source region within the body region. The method includes forming dielectric features (for example, element 23, 231, 32, 62, 322, 334, 411, 420, 421, 501) in spaced relationship with the semiconductor material, where the dielectric features form stressed regions that propagate stress in proximity to the channel region.

Those skilled in the art will also appreciate that according to a further embodiment, the step of forming the dielectric features in the method described in preceding paragraph comprises the steps of forming a contact trench extending through the source region to form first and second source region portions and forming a dielectric layer overlying exposing sidewall and lower surfaces of the contact trench, where the dielectric layer has thicker portions (for example, element 62) overlying the sidewall surfaces adjoining the first and second source regions portions, and where the dielectric features comprise the thicker portions.

Those skilled in the art will also appreciate that according to a still further embodiment, the step of forming the trench control structure in the method described in the paragraph [0053] comprises the steps of forming a hard mask layer (for

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example, element 91) overlying the major surface and having an opening, forming a trench within the semiconductor material through the opening, forming the gate dielectric layer overlying sidewalls of the trench, and forming the gate electrode recessed within the trench below the major surface. Also, where the step of forming the dielectric features comprises oxidizing upper portions of the sidewalls of the trench using the hard mask layer as an oxidation mask to form the dielectric features (for example, element 411) overlying portions (for example, element 418) of the major surface adjacent the trench and below the hard mask layer; and where the step of forming the source regions comprises forming the source regions within the body region in proximity to the dielectric regions and the gate electrode. In addition, the method further comprises the steps of forming contact trenches adjacent the source regions, where the forming the contact trenches step forms sloped sidewalls (for example, element 331) along portions of the source regions, and forming contact layers within the contact trenches.

In view of all the above, it is evident that a novel device and method is disclosed. Included, among other features, is forming one or more structures in a control structure, contact structures, or current carrying regions that propagate stress within certain regions of the device to provide the unexpected advantage of improving carrier mobility and reducing on-resistance. For example, placing a dielectric film within a conductive gate electrode in proximity to a channel region of a vertical power MOSFET device increases carrier mobility within the channel region.

Although the subject matter of the invention has been described and illustrated with reference to specific embodiments thereof, it is not intended that the invention be limited to these illustrative embodiments. Those skilled in the art will recognize that modifications and variations can be made without departing from the spirit of the invention. Therefore, it is intended that this invention encompass all such variations and modifications as fall within the scope of the appended claims.

We claim:

1. A semiconductor device comprising:

a region of semiconductor material having a major surface; a trench control structure in the region of semiconductor material including a gate dielectric layer adjacent sidewall surfaces of the trench control structure and a gate electrode comprising a first conductive material adjoining the gate dielectric layer;

a body region within the region of semiconductor material and adjacent the trench control structure, where the trench control structure is configured to provide a channel region within the body region, where the channel region includes a source end and a drain end;

a source region within the body region having a first side adjacent the trench control structure and a second side opposite to the first side; and

a first feature comprising a material other than the first conductive material encased completely within the gate electrode, where the first feature is configured to induce stress within portions of the channel region, and wherein the first feature comprises:

a base portion; and

a pair of side portions extending from the base portion.

2. The device of claim 1, where the first feature comprises dielectric material, and where the source end of the channel is vertically aligned with the drain end of the channel.

3. The device of claim 1, where the base portion is thicker than the side portions.

4. The device of claim 1, where the trench control structure further includes a shield electrode below the gate electrode,

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where the shield electrode is separated from the region of semiconductor material by a dielectric layer.

5. The device of claim 4 further comprising a second feature within the shield electrode, where the second feature is configured to induce stress within a drift region of the semiconductor device, and where at least one of the first and second features comprises a dielectric material.

6. The device of claim 1 further comprising a second feature adjoining the second side of the source region, where the second feature is configured to induce stress in proximity to the source end of the channel region.

7. The device of claim 1 further comprising second features adjacent to opposing corners of the gate electrode in proximity to the drain end of the channel region and configured to induce stress within the drain end of the channel region.

8. A semiconductor device structure comprising:

a region of semiconductor material having a first conductivity type, a first major surface, and a second major surface opposing the first major surface, where a portion of the region of semiconductor material is configured as a drain region;

a trench structure within the region of semiconductor material comprising a shield electrode in a lower portion of a trench, where the shield electrode is separated from the region of semiconductor material by a first dielectric layer; a gate electrode formed in an upper portion of the trench, wherein the gate electrode is separated from the region of semiconductor material by a second dielectric layer and separated from the shield electrode by a third dielectric layer;

a body region having a second conductivity type opposite to the first conductivity type in the region of semiconductor material and adjacent to the trench structure, where the gate electrode is configured to form a channel region within the body region;

a source region of the first conductivity type in spaced relationship with the body region having a first side adjacent to the trench structure and a second side opposite to the first side;

a first feature within the gate electrode and comprising a material configured to propagate stress within the region of semiconductor material adjacent to the trench control structure;

a second feature within the shield electrode and comprising a material configured to propagate stress with the region of semiconductor material within a drift region of the structure; and

a third feature between the gate electrode and shield electrode and comprising a material configured to propagate stress within the region of semiconductor material proximate to a drain end of the channel region.

9. The structure of claim 8, where the third feature adjoins a surface of the gate electrode.

10. The structure of claim 8, where the third feature adjoins a surface of the shield electrode.

11. The structure of claim 8, where the first feature comprises a plurality of spaced-apart stripe-like shapes.

12. A semiconductor device comprising:

a region of semiconductor material having a first major surface;

a trench control structure in the region of semiconductor material including a gate dielectric layer adjacent sidewall surfaces of the trench control structure and a gate electrode comprising a first conductive material adjoining the gate dielectric layer;

a body region within the region of semiconductor material and adjacent the trench control structure, where the

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trench control structure is configured to provide a channel region within the body region;
 a source region within the body region having a first side adjacent the trench control structure and a second side opposite to the first side; and
 a first feature comprising a material other than the first conductive material within the gate electrode, where the first feature is configured to induce stress within portions of the channel region, and wherein the first feature comprises:
 a base portion; and
 a pair of side portions extending from the base portion, where a portion of the gate electrode is between opposing inner surfaces of the pair of side portions.

13. The device of claim **12**, where the first feature comprises dielectric material, and where the device further comprises a first electrode electrically coupled to the source region proximate to the first major surface and a second electrode electrically coupled to the region of semiconductor material on a second major surface opposite to the first major surface.

14. The device of claim **12**, where the base portion is thicker than the side portions.

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15. The device of claim **12**, where the first feature is embedded within the gate electrode.

16. The device of claim **12**, where the trench control structure further includes a shield electrode below the gate electrode, where the shield electrode is separated from the region of semiconductor material by a dielectric layer.

17. The device of claim **16** further comprising a second feature within the shield electrode, where the second feature is configured to induce stress within a drift region of the semiconductor device, and where at least one of the first and second features comprises a dielectric material.

18. The device of claim **12** further comprising a second feature adjoining the second side of the source region, where the second feature is configured to induce stress in proximity to the source end of the channel region.

19. The device of claim **12** further comprising second features adjacent to opposing corners of the gate electrode in proximity to the drain end of the channel region and configured to induce stress within the drain end of the channel region.

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